

Technological Advances and the Next 50 Years of Cardiology

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THINKING ABOUT THE FUTURE

Think of every belief you have about health care, every assumption (e.g., "I get sick, I go to the doctor . . ."). Now, turn each one over, pull it inside out, imagine how it could be made false (e.g., "What if I don't wait until I am sick? What if the doctor comes to me? What if the help that comes is not a doctor? How could that be? . . .").

This is the future of healthcare. The combination of demographic shifts and cost pressures and a flood of new technologies—both biological and digital—promise that the new century and the coming generation will see the creative destruction and rebirth of what we know today as health care.

In no field is this more true than in cardiovascular medicine, situated as it is at the nexus of the most advanced technologies, the most expensive techniques, the conditions most sensitive to changing lifestyles and demographics, and the deepest scientific understandings.

In the coming years, and even during just the next decade, cardiovascular medicine will undergo radical changes in technique and understanding, even as health care undergoes radical changes in structure, payment systems, and information flow. Cardiovascular medicine will never again be what it was.

Yet we can make no specific predictions; crystal balls do not work. The future is unknown. Whatever the future of cardiovascular medicine is, it will not be exactly the way we paint it here. There are too many unknowns and even unknown unknowns.

So, how can we think about the future at all? We can create scenarios, reasonably plausible depictions based on a mixture of current breakthroughs, promising current research, and thoughtful extrapolations from current research. We can offer more detailed pictures of how events might unfold if current research produces results. Finally, to support these future images, we can offer an overview of where we are now: today's most promising areas of research and their possible future developments.

SCENARIOS

2009. At 60, you actually feel better than you did at 50, because of exercise, plenty of sleep, moderate habits, and the fact that you quit smoking at 50. But you have not been to the doctor much lately, so when you ask your physician to authorize a physical examination, you get a bit of a surprise. You expected more probing, a detailed talk with the doctor, and maybe some tests of blood or urine. Instead, the technician pricks your finger, takes a single drop of blood with a hand-held device the size of a computer mouse, and says, "Thank you. That will be all." Two minutes later, as you are still putting the bandage on your finger, the technician pops back into the room, hands you a printed slip, and says, "You're going to have to come talk to the life-stylist. You have no symptoms yet, but your genome says you're heading for heart disease."

2024. At 75, you still feel better than you did at 50, again because of exercise, plenty of sleep, and moderate habits as well as breakthroughs in antiglycosylation therapy. The man sitting next to you on the rocket plane to Mumbai seems quite normal, until the conversation you are having with him takes an odd twist, and you swap medical histories. You learn that he has a pig heart, and his arteries are swarming with "smart dust" that constantly reports on his condition, directly over the Internet, to his physician's database. These facts strike you as strange, a coincidence worthy of comment, because you have a pig heart, too. In fact, the man tells you, it is not strange at all anymore.

2049. At 100, you still feel better than you did at 50, still because of exercise, plenty of sleep, and moderate habits as well as breakthroughs in antiglycosylation therapy, whole-sale organ replacement in your eighties, and the nanolabs in your blood stream that manufacture pharmaceuticals as needed and constantly top up your telomerase, the enzyme that makes your cells immortal. With all of this help, your cardiovascular system ticks like a grandfather clock, and you never give it a second thought. You have given up on retirement. Who could afford it anyway, with so many Baby Boomers hanging on past 100?

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IMAGES OF THE NEAR FUTURE: 1999–2009

Genomic revolution. It is 2009. During the past 10 years, the unraveling of the human genome has turned out to be the Rosetta Stone of the human body. The work of the Human Genome Project, together with the work of such private firms as Celera and Human Genome Sciences—to parse the genome at the turn of the century—was a true turning point in medical history and in the history of cardiovascular medicine.

Every disease—in fact, every state of the human body—is the result of some genes expressing proteins and some genes suppressing other genes or modifying proteins expressed by other genes. The picture will never be simple, but eventually our understanding of the human genome will tell us what actually is happening in our cells. In this way, genomics (the study of the genome), proteomics (the study of the full complement of human proteins), bioinformatics (the techniques of gathering and processing all of this knowledge), and systems biology (the study of how all of these processes work as a complex adaptive system) are fundamentally different from all medical studies preceding them. Other studies dealt with effects; whereas these studies are the first to give us a direct look at the actual biochemical pathways of human development, health, and disease.

In cardiovascular medicine, the results of these genomic studies have been realized in two main paths: predictive diagnostics and pharmaceuticals.

PREDICTIVE POWER OF GENOMICS. Genomics and bioinformatics have given cardiovascular specialists a powerful new tool—the ability to predict heart disease even decades before symptoms appear (1).

By the end of the decade, inexpensive hand-held biosensors had been introduced and were capable of detecting a wide range of diseases within minutes by analyzing a drop of blood, urine, saliva, or breath or even by bouncing micro-radar off of the skin (2). The core of this hand-held device is the “lab on a chip” (a miniature chemical laboratory as small as 3 mm square) combined with a micro-array chip that fluoresces in patterns that advertise the presence of particular proteins or gene expressions and an analysis chip that compares the pattern of genes or proteins expressed to known patterns associated with particular disease states (3,4). Some chips search for tell-tale single-nucleotide polymorphisms (SNPs), which are patterns of tiny gene mutations that have been shown to be predictive of heart disease. Pharmacogenomic chips search for SNPs that tell how the patient will respond to particular drugs.

Pharmaceutical firms, as recently as the early 1990s starved for candidate compounds to test, have been wading through tens of thousands of possibilities, using the growing areas of genomics, proteomics, bioinformatics, and automated compound searches. The resulting flood of powerful new pharmaceuticals has begun to render many surgeries unnecessary:

- The use of cholesterol-controlling statins steadily increased throughout the decade as knowledge of their benefits spread among generalists, prices fell, and generic brands appeared;
- Angiogenesis drugs, such as vascular endothelial growth factor (VEGF), obviated the need for much bypass surgery by growing new arteries on damaged hearts;
- Anti-angiogenesis drugs (e.g., endostatin), locally implanted in arterial plaque, inhibit its growth;
- Myogenesis drugs rebuild damaged heart muscles;
- Antiglycosylation therapies prevent the cross-linking that weakens aging heart muscle;
- New vaccines raise high-density lipoprotein (HDL) levels to help stave off heart disease;
- New genomic therapies repair damage after a myocardial infarction and prevent the mass apoptosis that commonly follows;
- A nicotine vaccine allows smokers who wish to quit smoking to rid themselves of the physical craving for cigarettes; and
- New antibiotics are used prophylactically to prevent chlamydia and other infections, which cardiovascular specialists continue to investigate as a cause of cardiovascular disease.

Nutriceuticals. These new surgical and pharmaceutical therapies have combined with the rapid rise in popularity of nutriceuticals, or so-called functional foods, that actively contribute to heart health. Margarines and cooking oils made with plant sterols and stanols, which “taste fat” but actually lower low-density lipoprotein (LDL) cholesterol and raise HDL cholesterol, have replaced butter, other cooking oils, and other fats in many packaged foods and fast-food offerings. Major packagers of common foods, from breakfast cereals to frozen foods, market “heart-healthy” lines high in plant sterols and stanols and flavonoid antioxidants (5–11).

Surgery. In the decade since 1999, surgical techniques and devices have continued their rapid improvements. Stents have proliferated into a wider range of sizes and are capable of working in smaller arteries. New materials have greatly reduced the incidence of restenosis. Catheters have likewise become smaller and more maneuverable, affording surgeons a wider range of insertion points and a plethora of capabilities, from the now-traditional angioplasty to the decade-old electrical killing of fibrillating cells, laser techniques to encourage the growth of new blood vessels, and the direct placement of new angiogenesis drugs.

Tools for performing surgery on beating hearts have proliferated from the few available in 1999 to dozens. In fact, most heart operations are conducted without stopping the heart.

Minimally invasive surgery and intervention techniques are now used for all routine heart surgeries, even intracardiac (inside the heart) surgery. Cracking the chest is reserved for rare and difficult cases or for full organ replacement.

Robotics. Surgical robots, first introduced in the late 1990s, have become common as well. All major hospitals use them for their greater precision and speed, lower cost, and shorter recovery times. Whereas the first robots either operated cameras and lights or were direct extensions of the surgeon's hands, robots are now more often actually performing surgery—cutting, clamping, and suturing at the surgeon's direction, guided by voice commands ("Robot, suture"), by the movements of a mouse on a screen (highlight the area, click on "suture"), or by programming based on pre-operation three-dimensional images.

Imaging. Imaging has continued the rapid improvement of the previous decades. Magnetic resonance (MR) images taken via catheter are now commonplace. Since the late 1990s, image-processing techniques have combined data from a wide variety of sources (including angiography, computerized tomography [CT], MR, electron-beam [EBCT], echocardiogram, and MR echocardiogram) to produce three-dimensional, scalable images (12,13). Ten years later, advances in processing power and software allow surgeons not only to see three-dimensional images of the patient's actual heart but also to tour the heart in "virtual reality" and in real time, even as they operate, without the necessity of placing a lens inside the body.

Replacement hearts. Electromechanical replacement hearts have become common. It is no longer unusual to see older people at the beach wearing battery packs at their belts and taking them off for a dip in the surf (14). The cost associated with these replacements is less than half of the cost of a human heart transplant (15). Less obvious are the thousands of people walking around with swine hearts, which are now beginning to be used in situations that previously would have called for reparative surgery (16–18). Equally important are the thousands of people with replacement coronary arteries constructed from bovine and swine collagen (19).

Patient data. Connecting heart patients with practitioners for daily check-ins through software, the Internet, and small, easy-to-use home monitors has become standard practice, widely praised for keeping patients stable and healthy while keeping costs down. For some higher-risk patients, daily monitoring is not enough. They conduct their daily business while wearing "smart clothing"—undershirts, bras, or belts that monitor basic vital signs, such as pulse. The moment that any dangerous pattern emerges (e.g., a racing pulse, fibrillation, or wide variations in heart rate), a nurse at the patient's disease management provider is alerted through the Internet or the cellular phone system and initiates a response (20).

Electronic medical records built around an industry-wide information standard have become the norm. In fact, most people carry their own records with them. Some carry the information in "smart cards" with embedded data chips. Others carry credit-card-size CD-ROMs that can be read

by any computer, or a card imprinted with a Web address and personal identification number that gives online access to their records (21).

Standardization of diagnoses and clinical practice. At the same time that these new techniques and treatments have revolutionized cardiovascular medicine, clinical practice has become more standardized across the U.S. and even around the globe. The massive efforts of the American College of Cardiology (ACC)-National Cardiovascular Data Registry™ (NCDR™) and other organizations in collecting, analyzing, and disseminating information have resulted in a general set of consensus guidelines. These guidelines evolve constantly with new in-the-lab medical research results and with new in-the-field information about outcomes (what actually happens when real people with real heart disease and real complications receive particular therapies). This widespread reporting system allows the specialty as a whole to stay continuously aware of unfolding best practices, and this concentrated data study dramatically narrows the range of unnecessary variation, thereby leading to higher standards of care and, in many cases, lower costs.

Diagnosis also has become far more standardized. The College has led a major drive to identify genomic and proteomic patterns that display a wide variety of types of heart disease or predict it years in advance.

THE NEXT GENERATION: 2009–2024

It is 2024.

In the face of an older population, the number of cardiac surgeries has actually fallen as the Baby Boom generation has aged. The maturing genomic revolution has led to an array of drugs that together have brought much of heart disease under pharmaceutical control.

Heart exchange is the single most common type of open-chest surgery. In fact, except for unusual circumstances, it is the only type. Swine hearts are now common in older people. After a furious ethical debate, the use of organs from pigs has surged from the few thousand of the first decade of the century to hundreds of thousands per year, supplanting virtually all types of surgery meant to repair a failing heart, including bypass grafting, resectioning, and valve replacements (22).

The mechanical alternative has improved greatly in a generation. Not only has it become far more reliable, but also it no longer needs to have its batteries recharged. Instead, it is driven, just like a native heart, by the body's own metabolism.

Neo-organs—replacement organs grown in the laboratory from the patient's own cells—have finally become a clinical reality. In a generation of slowly expanding experiments, researchers have moved from growing thin sheets of heart muscle capable of sustaining a heartbeat to growing entire hearts, complete with vessels for carrying the blood supply, shaped over armatures that then dissolve (23).

The first nanomachines have now entered cardiovascular medicine, repairing and clearing arteries as well as delivering pharmaceuticals to precisely targeted sites (24–28). Nanotech has also produced “smart materials,” used for arterial walls, connective tissue, and even replacement muscle tissue, that mimic natural human tissue in adapting to their site and responding to hormonal and nervous signals (29).

Nanotechnology has also produced sensing devices the size of bacteria, covered with a protein skin that mimics human blood cells. Injected into the body, these “smart-dust” sensors circulate harmlessly in the bloodstream, recording body chemistry, hemodynamic flow and pressure, and whatever else they had been programmed to look for. They report the information to outside monitors by constructing characteristic information signatures easily detected by the inexpensive monitors in the shape of full-length mirrors, scanners, or the next generation of “smart clothing” (30).

Biotechnology has produced harmless cigarettes laced with nonaddictive nicotine substitutes, its tars and multiple other substances subtly altered to render them harmless while still satisfying to the smoker.

“Just-in-time” knowledge. Over this quarter century, the ACC-NCDR™ has evolved into the single most powerful and centralized tool for managing and combating heart disease. It catalogues outcomes of millions of cases across the U.S. and around the world. It steadily turns those outcome studies into practice guidelines and disseminates them to primary practitioners and specialists alike.

At the same time, the ACC-NCDR™ has participated in identifying the genomic and proteomic fingerprints of every variety of cardiovascular disease, allowing nearly instant and nearly certain diagnosis.

As the baby boomers age, the demand for cardiovascular knowledge and care rapidly increases, and many boomer cardiologists retire. Encouraging more medical students to enter the specialty is important and useful, but insufficient, so the ACC has moved aggressively to use technical means to overcome the problem.

By 2015, the ACC-NCDR™ has built genomic fingerprints, more traditional diagnostic criteria, and its practice guidelines and scientific notes into diagnostic-assistance software that is constantly updated over the Internet. By answering a series of questions and entering test results, a primary practitioner or nurse can diagnose a patient’s heart problem as if the most skilled specialist were standing at his or her elbow.

One version of the software watches the patterns of information that physicians or nurses enter into a patient’s electronic record. When patterns emerge that suggest a different diagnosis or therapy, the software comes to the fore to ask questions and offer “just-in-time” information tailored to the particular patient and the clinical situation.

Spreading accurate, useful cardiovascular clinical knowledge as widely as possible through every technique that

works has become a primary goal of the College’s NCDR™ and the ACC in general.

Altogether, the field of cardiovascular medicine is more important than ever, as rapid advances in organ replacement, pharmaceuticals, telomerase therapy, and antiglycosylation therapy have combined to produce extraordinarily youthful aging baby boomers. The boomers see opening up to them the possibility of living much longer than any previous generation, and they will pursue any therapy at any cost—paid for by them, by their insurance, or by society—that will lengthen their lives.

OUR CHILDREN AND GRANDCHILDREN: 2024–2049

It is 2049.

Heart replacement surgeries, which peaked about 2024, are now almost nonexistent. Today, few hearts, whether native human hearts or the old xenotransplants, become damaged enough to need surgical repair or replacement.

The tremendous and continuing exploration of the genomic roots of heart disease have brought a continuous and rapid improvement in prediction, diagnosis, and pharmaceutical therapies.

By the 2020s, most people were being scanned annually (and those at high risk, more often) by technologists armed with hand-held genomic scanners. In the early years, the information led to recommendations for lifestyle changes, such as shifts in diet, exercise patterns, smoking, or other consumption habits.

By the 2030s, however, the hand-held scanners were no longer needed. Injectable “smart dust” had advanced to the point that it could continually report, and deliver as part of the daily routine, genomic shifts and changes in language that the consumer could understand. At the same time, the recommendations changed from diet and lifestyle to pharmaceuticals.

Pharmaceuticals had become so successful at preventing cardiovascular damage—and repairing any damage that did occur—that diet and lifestyle changes were no longer necessary. People could eat whatever they wanted, smoke, and avoid exercise while their cardiovascular systems pumped away like antique mechanical Swiss watches—as long as they took the pharmaceuticals the mirror prescribed.

By the 2040s, even the pharmaceuticals were rapidly becoming outmoded. Nanotechnology had gone beyond “smart dust” to universal bio-assemblers. Floating in the bloodstream, these minuscule factories could act on genomic information derived on their travels through the bloodstream, combined with information and reprogramming continually and automatically downloaded from the Internet as medical science arrived at new understandings. The bio-assemblers could put together the needed pharmaceuticals on demand from locally available chemicals in the bloodstream.

As the ACC approaches its centenary celebration in 2049, it finds itself engaged in a far-reaching and furious

debate within its ranks. The question is "Should the ACC reconstitute itself in some new shape for its second century?" Some radicals even suggest that the College should be abolished, that the specialty of cardiovascular medicine itself should go the way of polio specialists. They argue that the understanding of the underlying genomic structures has advanced so far that there is very little study, and few techniques or therapies, that are truly specific to the heart. Cardiac surgery has all but disappeared. Almost all heart therapy is now preventive and is carried out either through pharmaceuticals (now considered old fashioned) or through information exchange to the universal bio-assemblers. By now, in the mid-twenty-first century, there are still many types of medical specialties; but the trend of the era is to build specialties not around organs or systems but around ways of looking at the overall system, such as genomics, proteomics, medical nanomics, systems biology, and bioinformatics.

But the voices of the mainstream argue that the College still has a mission that is central to the practice of medicine. The heart, with its attendant systems, remains the central driver of the body, with their own special problems. In fact, during the half-century from 1999 to 2049, the ACC has rapidly evolved, linking these new sources of knowledge directly to the actual field practice of cardiovascular medicine. It is this rapid, practical response that has succeeded in taming what once was the greatest killer of all.

REALITY CHECK

All discussion of the future is, of course, some species of speculation. No one can truly know the future. These speculations, however, are based on current research efforts and the possibilities they bring to light extrapolated into the future.

Most of the near-term possibilities are based on the reasonable supposition that discoveries and techniques that are new today will be refined during the next 10 years. They will come into common use to the extent that they are found to be useful, safe, and affordable. Most of the possibilities from 10 to 25 years in the future are extrapolations from current research and are necessarily more speculative.

Beyond 25 years from now, we are making reasonable guesses. In most cases, results that depend on engineering (e.g., robotics, imaging) come more quickly and more certainly than results that directly involve biology (e.g., neo-organs) or results that depend on popular awareness (e.g., switching to cholesterol-controlling margarines). Biology and sociology are far more complex than engineering.

In all cases, of course, the speculations spring from where we are today.

Genomics. A rough draft of the complete human genome should be ready by mid-2000, and a final draft within two years (31). Human Genome Sciences, Inc., claims to have already mapped nearly all of the genes that actually express in the human body (32). A group of 11 major pharmaceu-

tical companies has founded the SNP Consortium with a \$45 million budget and the goal of mapping an estimated 300,000 SNPs.

The task of identifying all of the proteins in the human body is also proceeding apace, complicated by the fact that estimates of their numbers range from roughly 100,000 (the number of human genes) to 100 million. Much of the enormous task of finding the patterns of genes, proteins, and SNPs that signal disease or genetic predisposition to disease remains to be done—and the task is highly complex.

However, it is not necessary to wait for all of the genomic information to be in place before it becomes clinically useful. Already, at the beginning of 2000, one biotechnology firm began offering a home DNA kit that would allow consumers to test their blood for SNPs that herald adverse drug reactions (33). According to the Biotechnology Industry Organization, by mid-1999 more than 80 pharmaceuticals derived from this information had already been approved by the Food and Drug Administration (FDA), more than 350 were in various stages of FDA testing, and more than 10,000 compounds have been identified as targets for testing as possible drugs over the next five years (34).

The examples of genomic drugs mentioned previously are in various stages of development:

- Cholesterol-controlling statins are available but underutilized (35–38);
- Several types of angiogenesis VEGF are in human clinical trials; early results have been mixed, but the idea still seems sound (39,40);
- Endostatin has recently been shown to be effective in forestalling the growth of arterial plaque (41,42);
- Myogenesis drugs, antiglycosylation therapies, and genomic therapies to repair damage after myocardial infarction are still in early research stages (43–46);
- An HDL-raising vaccine has been successful in animal trials (47,48);
- A nicotine vaccine has been successfully tested in laboratory rats, with human trials planned within two years (49);
- Whether prophylactic antibiotics might help prevent cardiovascular disease is under active investigation (50,51).

Surgery. Stents are in common use today. Interventionist and minimally invasive techniques are becoming more common (52).

Beating-heart surgery was introduced in 1998 (53–56). Robotic heart surgery, pioneered by U.S. firms, entered the commercial market in Europe in 1998, and human clinical trials were launched in the U.S. in 1999. Early experience has proven that robots, with their more-than-human dexterity, stability, and precision, can execute through minimally invasive ports some operations for which human surgeons would have to open the chest (e.g., Atrial-Septal Defect [ASD] closure) (57,58). It is not yet clear whether robotic surgery will ever become faster, more cost effective, or better for the patient than traditional surgery.

The single largest question about the future of cardiac surgery is how soon pharmaceutical advances will actually cause a drop in the volume of procedures. Clearly, if even some of the current genomic lines of research produce useful results, then those pharmaceuticals will obviate the need for many of today's surgical and interventionist procedures. Successful VEGF drugs in particular could replace coronary artery bypass grafts (CABGs), the single most common major operation in the nation. The population is aging, yet the bulk of the baby boom generation will not reach the prime age for heart disease until after the year 2015. This question is of major importance for planners designing new surgical units and for medical schools educating cardiac surgeons. This area is a prime candidate for computer modeling that would test the sensitivity of various assumptions.

Imaging. Experimental techniques can combine data from different sources to produce three-dimensional, scalable images from any point of view with any level of transparency for different types of tissue (59–61). The extrapolation of these images into real-time, three-dimensional, noninterventionist “fly-throughs” of the human body largely depends on further large advances in computing capacity. Although Moore's Law (which postulates an 18-month doubling period in computer power) is experiencing some fundamental physical problems, a range of investigations, ranging from single-molecule logic gates to quantum computing, allows us to imagine that Moore's Law will continue to operate, and computing power will continue to increase at a rapid pace (62–66).

Replacement hearts. Electromechanical replacement hearts are ready to enter human clinical trials in this calendar year (67). The idea that such hearts may someday be able to beat without an outside battery is purely speculative. Clearly, the human body has such power available, as it powers the native heart, but so far no artificial muscle that derives energy from native metabolic processes has been developed.

Swine hearts are similarly ready for human trials, according to the chief proponent of the technique, Dr. Jeffrey Platt of the Xenotransplant Institute at the Mayo Clinic, in Rochester, Minnesota (68). The concern that swine hearts might introduce porcine retroviruses into humans has proven ill-founded (69).

Research into building neo-organs has shown that heart muscle cells can be cultured outside of the body, grown on a matrix into a thin, continuous sheet, and made to beat as a unit (70). Other researchers have constructed arteries of bovine and porcine collagen coated with heparin (71). How long these experiments will take to produce full lab-grown hearts is impossible to tell, but the possibility seems on the one hand to be quite real and on the other hand to be at least a generation in the future.

Heart replacement may well become the dominant form of heart surgery, but looking ahead from 2000, it is not clear what the specific replacement will be—a mechanical heart, a swine

heart xenograft, or a heart grown from the patient's own fibroblasts. A generation ahead, these operations may ultimately be superseded by directly inducing fibroblasts to grow muscle, valve tissue, or arteries in situ to replace damaged tissue.

Nanotech. Nanotechnology is still in its infancy—part theory, part basic design, and part experiment. Theoreticians have produced plausible designs of gears, pumps, and other basic mechanical structures built from altered hydrocarbon molecules. Experimenters have built molecular-scale propellers and ratchets. At least one experimenter claims to have built basic shapes (e.g., cubes, octohedrons) as well as a crude logic gate by altering DNA molecules (72). Although the field seems promising, no one has yet built a working nanomachine of any kind. We are at least a generation away from useful nanoproducts.

Patient data. A number of firms have pioneered the use of the Internet, in combination with blood pressure cuffs and other devices, to maintain constant contact between chronic heart failure patients and their health providers. Initial tests show significant drops in emergency room visits, hospitalizations, and cost as well as significant increases in functional ability (73–76).

Smart cards, wallet-size CD-ROM cards, and Web sites that store patient medical records are already a reality. Unfortunately, industry-wide technical standards for electronic medical records have not yet been adopted, and a majority of health care systems still use paper records. The blocks to changing these practices are not technical but political, cultural, and economic.

Standardization of diagnoses and clinical practice. The ACC's NCDR™ is one of the College's most important recent initiatives. Together with the ACC/American Heart Association Task Force on Practice Guidelines and the ACC expert consensus documents, the NCDR™ is intended to become a major force to spread best-practice knowledge throughout the specialty.

“Just-in-time” knowledge. The pieces of a “just-in-time” knowledge system already exist. These include rapidly growing databases of diagnostic and practice guidelines; “diagnostic assistance” software; experiments with software that can recognize patterns in diagnosis, treatment, or pharmaceuticals and offer new knowledge; Internet-ready personal digital assistants (PDAs) designed for medical use; and the World Wide Web to connect together the PDAs and the databases (77–82). Developing these pieces into a widely accepted, seamless system that would be a major enhancement of clinical practice is no longer a technical problem but an economic and cultural one.

Life extension. Will all of these medical and technical breakthroughs actually extend people's lives? The answer is far from obvious, because it is a general-systems question, and our knowledge is largely about subsystems. Even curing

heart disease entirely would only add a few years to the lives of bodies that are prey to many other diseases as well as to the multiple systemic degradations and failures that are part of the aging process. Yet the kind of deep understanding of human biochemistry that would lead to a complete cure of heart disease could not exist in a vacuum: such deep understanding would undoubtedly lead to cures, preventatives, or powerful therapies for many other diseases and conditions. Furthermore, some studies, such as those on telomerase and glycosylation, seem to offer insight into the aging process itself.

It is on this general-systems question that our conclusions are clearly the most speculative. Yet, we believe that it is quite possible that the next 50 years will see the introduction of therapies that will allow people to live significantly longer lives.

SUMMARY

The fiftieth anniversary of the ACC and the end of the twentieth century are arbitrary points in time, yet they seem to coincide with a true watershed. The last 50 years have

brought a rush of new techniques and understandings that have, for the first time, given cardiovascular specialists real tools to prevent and fight cardiovascular disease. Only now, for the first time, has science begun to understand exactly what happens when plaque forms in an artery, when heart muscle fibers cross-link and weaken, when an atrial chamber fibrillates, and when heart muscle cells die en masse after a heart attack. We are beginning to track down the actual chemical, mechanical, and electrical pathways by which the heart is damaged or dies. When we can interfere with those pathways and stop the chain of events, we will have defeated heart disease.

Imagination is rapid, but progress is often both uncertain and slow because of the many constraints of cost, regulation, and time needed to test and evaluate new developments. Yet we can now foresee a future in which medical science might actually defeat cardiovascular disease the way it has defeated polio, smallpox, and other serious scourges of the past.

Technological Advances and the Next 50 Years of Cardiology: Ethics and Privacy

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Technology is ineluctably human. It could be said that our ability to produce technology is what defines us as humans. It is who we are.

Technology is driven by our desires. So, it is not surprising that every new development prompts debates about ethics, morality, and philosophy. These debates can be boiled down to the questions, "Who are we, as humans?" and "What do we really want?"

These questions became especially vivid during the critiques and discussions around early versions of this report. For instance, some new developments raise the possibility of extending the human life span beyond its current limits. That possibility is not at all a consensus goal among physicians or cardiovascular specialists. Some consider it morally suspect.

The moral, ethical, legal, and social issues raised by these new technologies include the following:

GENOMICS

Privacy. If it becomes possible by mapping the SNPs in your genome to determine not only which diseases and syndromes you have now but also which ones you are likely

to have in the future, to whom should this information be made available? Your insurers? Your employer? Your prospective employers? Your school? Your spouse? Your dating partners? Your friends and neighbors? Government agencies?

Wherever we draw the bright line of privacy, how should we enforce it? What should we do about the black market in genomic information that will inevitably develop?

Do we have a right to not know our own future? If you could know your own health future decades in advance, would you want to? Will we be able to refuse the knowledge, or will it be forced on us?

Cost. Already, one of the greatest problems that physicians report in getting patients to comply with their drug regimens is that the patients simply cannot afford the drugs. Many older people, especially those who are living on fixed incomes and facing multiple health problems, have to choose between eating and taking a full course of their heart medicine. The new drugs derived from genomic information may greatly exacerbate this problem. Some will be inexpensive. Many will be expensive but cheaper than the